Clay Minerals of the Jurassic Arapien, Twist Gulch, and Morrison Formations of Central Utah

by

Deana D. Chapman

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Thesis Advisor

Rodney Tettenhorst

Department of Geology and
Mineralogy

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ABSTRACT

Twenty-one samples from the Jurassic Arapien, Twist Gulch, and Morrison Formations in central Utah were collected during the summer of 1980. The whole fractions of these samples were x-rayed in order to determine the major constituents. All contained quartz and feldspar; most contained calcite and dolomite. Gypsum, halite, and either hematite of goethite occurred in some. Clay fractions of each sample were x-rayed twice, once before solvation in ethylene glycol, and after solvation, in order to classify the clay minerals as either smectite, illite, kaolinite, chlorite, or mixed-layer clays. Although no clay group was completely confined to any single formation, smectites occurred mainly in the Morrison, with minor occurrences in the Twist Gulch deduced from very weak peaks. Mixed-layer clays occurred in both the Arapien and the Twist Gulch, but not in the Morrison. The Arapien and the Twist Gulch could be distinguished from one another by particle size, as the Twist Gulch contained a smaller percentage of clay sized particles.

INTRODUCTION

In the early 1920's, E. M. Spieker began field studies of the central Utah region. He and his students designated the Jurassic deposite of the area as the Arapien, Twist Gulch, and Morrison(?) Formations. Although each has its own distinctive lithology, all contain red mudstones which appear similar in the field. The objective of my study was to determine if the clay content was distinctive of a formation and, hence, could be used to distinguish formations in areas where other methods of differentiation were less certain.

STRATIGRAPHY

The Arapien Shale is the oldest of the Jurassic deposits of central Utah. It consists mainly of light gray fissile shale interbedded with fine grained, well sorted quartz sandstone. In places the sandstone has a reddish cast. A thick, red, non-resistant mudstone overlies the shale and is considered part of the formation. Gypsum occurs throughout. The Arapien is believed to be a marine deposit.

The Twist Gulch Formation is mid-Jurassic in age. It is predominantly fine grained, friable, brownish-gray sandstone and siltstone alternating with reddish-brown shale. Beds of less resistant red siltstone and mudstone occur throughout. The unit is marine.

The Morrison(?) Formation is of late Jurassic age. It consists of coarse grained yellowish and bluish-red sandstone interbedded with massive conglomerate containing quartz, chert, and carbonate clasts. Mudstone is present in places, as is gypsum. It is assumed to be of fluvial origin. There is some doubt as to its equivalency with the Morrison Formation in other areas due to a lack of lateral continuity. It is, however, in the correct stratigraphic position and has the vivid pink, orange, and purple colors which characterize the Morrison elsewhere.[1]

SAMPLES

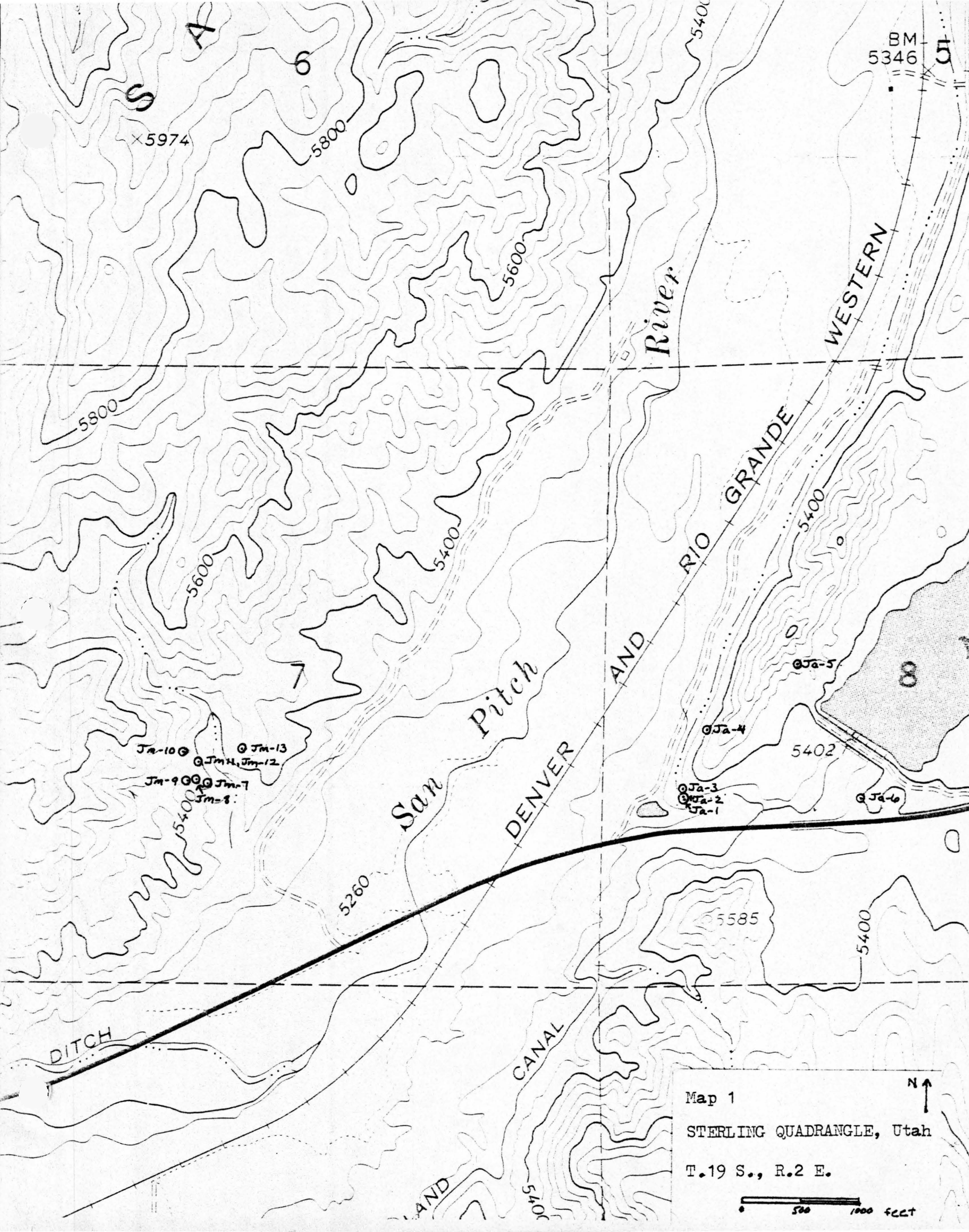
Location

Twenty-one samples were collected in central Utah at four localities. Six samples were taken in section 8, T.19 S., R.2 E., in Sterling Quadrangle (Map 1). Samples 7 through 13 were taken in section 7, T.19 S., R.2 E., in Sterling Quadrangle (Map 1). Sample 14 was taken in section 31, T.21 S., R.1 E., in Salina Quadrangle. No map was available to plot the exact location of this sample. It was taken from the first red hill north of Interstate 70 0.2 miles east of the city of Salina, Utah. Samples 15 through 21 were taken in Salina Canyon, section 33, T.21 S., R.1 E., in Salina Quadrangle (Map 2).

Description of samples

Ja-1	Yellowish gray resistant shale; moderately fissile.
Ja-2	Gray blocky shale; stratigraphically younger than Ja-1.
Ja-3	Gray-green platy shale; less fissile, less indurated, and less silty than Ja-1; stratigraphically younger than Ja-2.
Ja-4	Gray-green shale; non-fissile; small thin chips; stratigraphically younger than Ja-3.
Ja-5	Gray blocky shale; stratigraphically older than Ja-1.

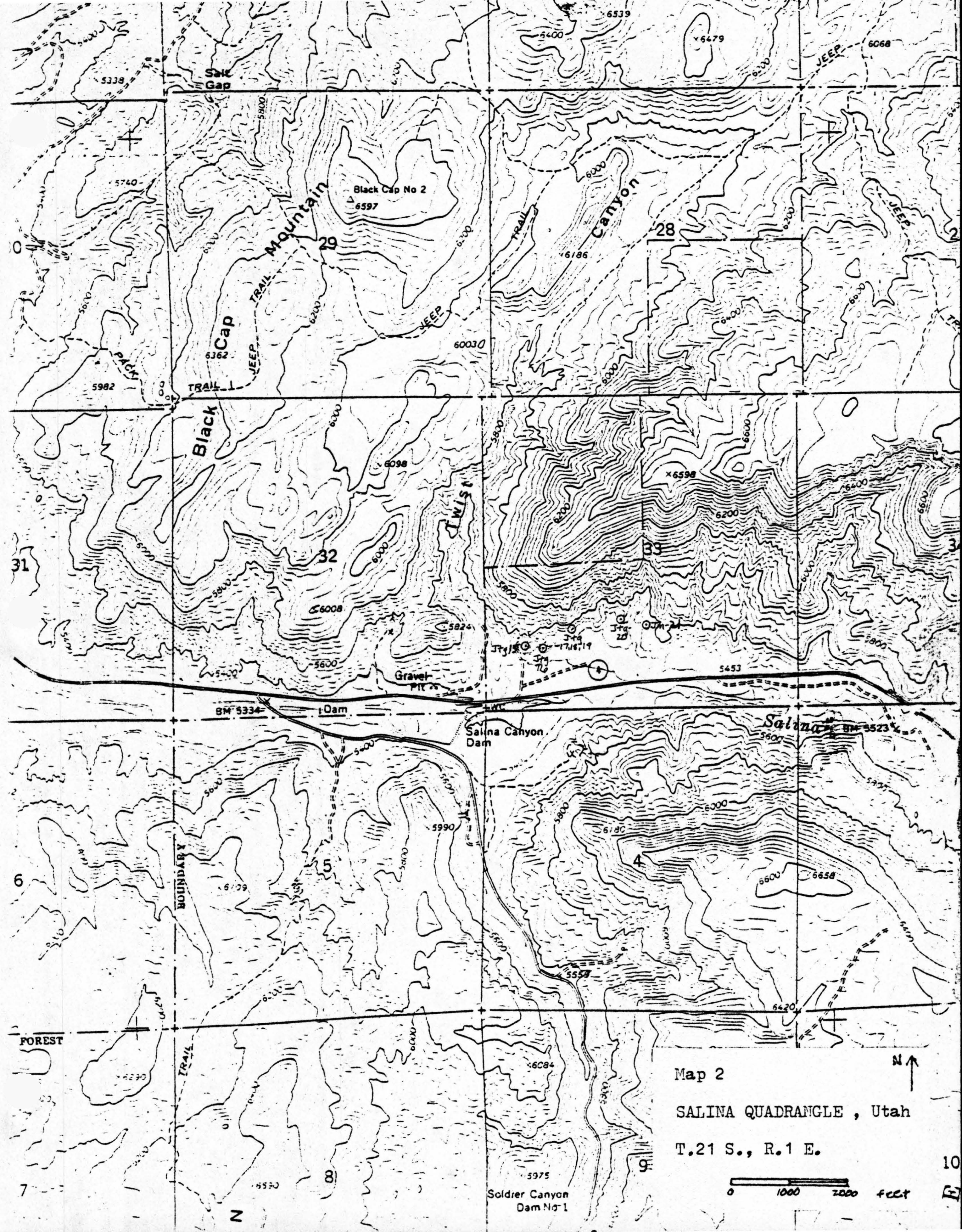
[1] Personal comment by Dr R. T. Tettenhorst.



Map 1

STERLING QUADRANGLE, Utah

T.19 S., R.2 E.



Map 2

SALINA QUADRANGLE , Utah

T.21 S., R.1 E.

0 1000 2000 feet

N

Ja-6	Red clay mottled with gray clay; contains gypsum; massive; possibly weathered.
Jm-7	Red and white clay; very clayey; appears purple from distance; possibly weathered.
Jm-8	Massive, purple clay; non-lithified; possibly weathered.
Jm-9	Massive, orangish-brown clay; contains limestone blocks; possibly weathered.
Jm-10	Massive, purple clay; very clayey.
Jm-11	Small reddish flakes in shale matrix.
Jm-12	Orange flakes in shale matrix; weathered.
Jm-13	Massive, gray and purplish-red clays; contains limestone; possibly weathered.
Ja-14	Red clay; slightly bedded.
Jtg-15	Silty, blocky, chocolate brown clay and shale; slightly weathered.
Jtg-16	Massive, soft, reddish clay; contains some gray clay; possibly weathered.
Jtg-17	Blocky, bluish-red clay and silt; harder than Jtg-16.
Jtg-18	Hard, reddish clay and silt; well indurated.
Jtg-19	Small, blocky, soft, reddish clay; possibly weathered.
Jtg-20	Small, dark reddish-brown shale; trace of greenish-gray shale.
Jm-21	Massive, bright purplish clay.

EXPERIMENTAL PROCEDURE

Sample Preparation

Each sample was hand ground to sand size, then was ground in a mechanical mortar for 10 minutes, resulting in a silt and smaller sized sample.

Whole Fraction Preparation

Oriented mounts were made by placing 0.2 g of sample and 2 ml of distilled deionized water in a glass vial. This was vigorously shaken. The solution was then placed on a glass slide by means of an eye dropper and was allowed to dry.

Powder mounts were made by placing a small amount of the sample in an aluminum mount which was backed by a glass slide. A second slide was used to pack the sample and to clear away excess sample. Care was taken to insure that the top of the sample was flush with the top of the mount.

Clay Fraction Preparation

4.0 g of sample was added to 300 ml of distilled deionized water and was washed once using an air filter system and ceramic tubes in order to decrease the concentration of any soluble salts. The sample was then added to 200 ml of distilled deionized water, and stirred up. Small amounts of a 10% solution of calgon and water were added to each sample to aid in dispersal of the sample (Table 1). The settling time necessary to obtain a 5 micron and less fraction was calculated by using Stokes' law (Jackson, 1956),

$$t = \frac{18nh}{g(S_p - S_l)D^2}$$

where,

t = time of fall (seconds)
n = viscosity of fluid (poises)
h = depth of fall (cm)
g = gravitational constant (980 cm/sec^2)
S_p = specific gravity of the particle (gm/cm^3)
S_l = specific gravity of the fluid (gm/cm^3)
D = spherical diameter of the particle (cm)

The following values were assumed in making the calculation:

n = .01 poises
S_p = 2.65 gm/cm^3
S_l = 1.00 gm/cm^3

For an "h" of 2 cm the settling time necessary to obtain a 5 micron and less fraction was calculated to be 14.8 min. Since this was an approximation each sample was allowed to settle for 15 min., at which time the top 2 cm were pipetted off, placed on a glass slide and allowed to dry. The slides were placed in a closed container containing ethylene glycol, and were heated at 50°C for 48 hours.

SAMPLE	CALGON (drops)	SAMPLE	CALGON (drops)
Ja-1	10	Jm-12	15
Ja-2	5	Jm-13	5
Ja-3	10	Ja-14	20
Ja-4	10	Jtg-15	10
Ja-5	10	Jtg-16	10
Ja-6	15	Jtg-17	10
Jm-7	10	Jtg-18	10
Jm-8	10	Jtg-19	10
Jm-9	10	Jtg-20	5
Jm-10	5	Jm-21	10
Jm-11	10		

Table 1. Calgon added to samples.

X-Ray Techniques

Both the powder mount and the oriented mount of two whole fraction samples, Ja-6 and Jm-8, were x-rayed. Ja-6 was chosen because its oriented mount appeared to be the best of all the samples, and Jm-8 because its oriented mount appeared to be the worst. There were no obvious differences in the two patterns of either sample, so it was decided that due to a lack of time, only the powder mounts of the other samples would be x-rayed. Samples 1 through 17 were x-rayed on a Phillips XRG 3100 generator equipped with a proportional detector, a pulse height analyzer, and copper radiation, at the following settings:

goniometer speed:	1° 2θ/min.
chart speed	1"/min.
voltage:	40 kV
amperage:	30 mA
time constant:	0.5 sec.
range:	1000 counts/sec.

Samples 18 through 21 were x-rayed on a different Phillips XRG 3100 generator equipped with a scintillation detector, a pulse height analyzer, and copper radiation, at these settings:

goniometer speed:	1° 2θ/min.
chart speed:	0.5"/min.
voltage:	35 kV
amperage:	15 mA
time constant:	1 sec.
range:	500 counts/sec.

The clay fraction slides where x-rayed twice; before and after glycolation. All clay fractions were x-rayed on the Phillips XRG 3100 generator with the scintillation detector, pulse height analyzer, and copper radiation with the following settings:

goniometer speed:	1° 2θ/min.	
chart speed:	0.5"/min.	
voltage:	35 kV	
amperage:	15 mA	
time constant:	1 sec.	
range:	samples 1-5:	250 counts/sec.
	samples 6-21:	1000 counts/sec.

Although the range varied with the sample, it was held constant for both the glycolated and non-glycolated pattern for any specific sample.

X-RAY ANALYSIS

Whole Fraction

Observed diffraction angles were converted to interplanar spacings by means of Bragg's law,

$$\lambda = 2d\sin\theta$$

where

λ = wavelength of radiation(1.54184 Å)
d = interplanar distance(Å)
θ = angle of reflection

Major peaks were identified as either quartz, feldspar, calcite, dolomite, or clay, with minor occurrences of gypsum and halite. Iron oxide (either hematite or goethite) could be observed in most of the red samples, but the peaks were very weak. A general survey of the major constituents of the whole fractions is given in Table 2.

Clay Fraction

The clay fraction consisted of particles with an equivalent spherical diameter of 5 microns or less. This reduced the mineral constituents other than clay, and emphasized the clay constituents. In order to identify the clay minerals, the x-ray pattern of the non-glycolated sample was compared with that of the glycolated sample. Smectite expands in the c-axis direction to about 17Å by the absorption of molecules of ethylene glycol between clay layers, whereas kaolinite, illite, and chlorite do not expand. Table 3 provides a listing of diffraction angles of both the non-glycolated and the glycolated samples, their corresponding interplanar spacings, and their identification. In most cases, no attempt was made to classify individual specimens in any more detail than into major groups.

The smectite group was identified by a (001) spacing of about 13Å which expanded to 17Å when solvated with ethylene glycol. In addition, peaks became much sharper and were heightened. Few of the samples showed ideal spacings, due to interlayer mixtures with illite, but samples from the Morrison approached ideal spacings in most cases. Sample Jm-10 appeared to be 100% montmorillonite. Optical methods were used in an attempt to ascertain its origin. Due to the structure of the mudstone, thin-section slides were extremely difficult to make. No relict structures or volcanic shards could be observed, probably due to the poor quality of the slides. However, the sample contained much biotite, indicating probable volcanic origin.[1]

The illite group was identified by a (001) spacing of about 10Å, with supporting spacings at integral high orders which do not shift when solvated in ethylene glycol. Illite peaks were broad rather than sharp, due to disordered and random interstratification of different micaceous minerals in the illite group (Keller, 1962).

Clay minerals of the kaolin group were identified by their 7Å spacing, which was relatively sharp in some cases but more often was broad.

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[1]Personal comment by Dr. K. O. Stanley

Members of the chlorite group were identified by their 14Å interplanar spacing, which did not change upon glycol solvation, and which gave an extremely sharp peak. Chlorite was found only in one sample, Ja-6. Other peaks were observed at 14Å but were very weak, and were probably the mica phase which had been stripped of potassium and expanded to 14Å.[1]

The large majority of the clays were mixed-layer clays. These appeared to be predominantly illite, with an approximate 10Å interplanar spacing, but which were somewhat modified by glycolation. Although their peaks did not shift, they became much broader, tapering off toward lower diffraction angles, indicating the presence of some interstratified smectite.

DISTRIBUTION OF THE CLAY MINERALS

The distribution of the clay groups is given in Table 4. From this it can be seen that clay minerals of the Arapien are predominantly mixed-layer clays, of the Morrison, smectite, and of the Twist Gulch, mixed-layer clays. While smectite is present in the Twist Gulch, it is either in small quantities or is very poorly crystallized, generating weak peaks. Kaolinite is present in all three formation, probably as a secondary product of weathering. Illite is generally not present without interstratification. In general, the Morrison can be separated from the other formations by the presence of smectite. While the Arapien and the Twist Gulch cannot be differentiated by the presence of specific clays, the quality and quantity of clay present does provide a means of separation. The Arapien contains mostly clay, with very little silt, and generates clear, relatively good peaks. The Twist Gulch is mainly silt, with very little clay. X-ray patterns of clay size material in the Twist Gulch are very poor, having small, non-descript peaks.

[1]Personal comment by Dr. R. T. Tettenhorst

	Ja 1	Ja 2	Ja 3	Ja 4	Ja 5	Ja 6	Jm 7	Jm 8	Jm 9	Jm 10	Jm 11	Jm 12	Jm 13	Ja 14	Jtg 15	Jtg 16	Jtg 17	Jtg 18	Jtg 19	Jtg 20	Jm 21
Quartz	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Potassium Feldspar	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Plagioclase Feldspar	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	
Calcite	x	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x	x	x
Gypsum								x		x											
Smectite							x	x	x	x	x	x	x								x
Illite	x	x	x	x	x	x								x	x	x	x	x	x	x	
Kaolinite			x		x				x							x				x	
Iron Oxide Hydrous or Anhydrous						x							x	x	x	x	x	x	x	x	
Halite	x	x	x		x	x								x	x		x	x			
Dolomite	x	x	x	x	x		x		x		x	x		x		x	x				

Table 2. Major constituents as determined by x-ray diffraction.

SAMPLE	GLYCOLATED		NON-GLYCOLATED		INTERPRETATION*
	2θ	d(Å)	2θ	d(Å)	
Ja-1	8.80	10.05	8.30	10.65	I/I-S
	12.45	7.11			Kaolinite
			17.80	4.98	I/I-S
	19.80	4.48	19.70	4.51	I/I-S
	20.80	4.27	20.90	4.25	Quartz
	23.10	3.85	23.10	3.85	Calcite
	26.70	3.34	26.70	3.34	Quartz
	27.90	3.20	27.90	3.20	Feldspar
	29.50	3.03	29.50	3.03	Calcite
Ja-2	8.65	10.22	8.80	10.05	I/I-S
			20.20	4.40	I/I-S
	20.80	4.27	20.90	4.25	Quartz
	23.10	3.85	23.10	3.85	Calcite
	26.70	3.34	26.60	3.35	Quartz
	29.50	3.03	29.50	3.03	Calcite
Ja-3	8.80	10.05	8.70	10.16	I/I-S
	12.30	7.20	12.40	7.14	Kaolinite
	19.70	4.51	19.85	4.47	I/I-S
	20.90	4.25	20.80	4.27	Quartz
	23.10	3.85	23.10	3.85	Calcite
	25.20	3.53	25.25	3.53	Kaolinite
	26.70	3.34	26.60	3.35	Quartz
	28.00	3.19	27.80	3.21	Feldspar
	29.50	3.03	29.50	3.03	Calcite
Ja-4	6.00	14.73	6.20	14.26	14Å Clay
	8.80	10.05	8.60	10.28	I/I-S
	12.50	7.08	12.35	7.17	Kaolinite
	17.80	4.98	17.75	5.00	I/I-S
	19.50	4.55	19.70	4.51	I/I-S
	20.80	4.27	20.70	4.29	Quartz
	22.00	4.04			Feldspar
	23.00	3.87	22.95	3.88	Calcite
	24.90	3.58			Kaolinite
	26.60	3.35	26.60	3.35	Quartz
	27.20	3.28	27.30	3.27	?
	27.80	3.21	27.80	3.21	Feldspar
	29.50	3.03	29.50	3.03	Calcite

Table 3. Observed d spacings and interpretations.

*Notation used for clays:

I/I-S: Predominantly a 10Å (Illite) peak which is broad and tailed to low 2θ and is modified somewhat by glycol, indicating the presence of interstratified Smectite.

14Å(w): A weak peak which is probably the mica phase which has been stripped of potassium and expanded to 14Å.

Chlorite: An extremely good 14Å peak which is not modified by glycol.

Smectite(x): A 17Å reflection. Fraction of 17Å given in parenthesis based on assumed random orientation.

I-S: Interstratified 14Å and 17Å, with neither predominant.

SAMPLE	GLYCOLATED		NON-GLYCOLATED		INTERPRETATION
	2θ	d(Å)	2θ	d(Å)	
Ja-5	6.10	14.50	6.15	14.37	14Å(w)
	8.65	10.22	8.70	10.16	I/I-S
	12.40	7.14	12.50	7.08	Kaolinite
	16.25	5.45	16.20	5.47	14Å(w)
	17.75	5.00	17.80	4.98	I/I-S
	19.95	4.45	19.65	4.52	I/I-S
	20.80	4.27	20.80	4.27	Quartz
	25.10	3.55	25.05	3.55	Kaolinite
	26.60	3.35	26.55	3.36	Quartz
	27.40	3.25	27.25	3.27	Feldspar
	27.80	3.21	27.90	3.21	Feldspar
	29.40	3.03	29.40	3.04	Calcite
Ja-6	6.00	14.73	6.10	14.49	Chlorite
	8.85	9.99	8.85	9.99	Mica
	12.40	7.14	12.40	7.14	Kaolinite
	17.85	4.97	17.90	4.96	Mica
	18.65	4.76	18.40	4.82	Mica
	25.00	3.56	25.00	3.56	Kaolinite
	26.70	3.34	26.90	3.31	Quartz
	27.80	3.21	27.80	3.20	Feldspar
	29.40	3.04	29.40	3.04	Calcite
Jm-7	5.20	17.00	7.00	12.63	Smectite(.8S)
	19.70	4.51	19.90	4.46	Smectite(.8S)
			20.35	4.36	Cristobalite(?)
	20.80	4.27	20.90	4.25	Quartz
	23.00	3.87	23.00	3.87	Calcite
	25.15	3.54			Anatase(?)
	26.55	3.36	26.60	3.35	Quartz
	29.45	3.03	29.45	3.03	Calcite
Jm-8	4.85	18.22	7.1	12.45	Smectite(.6S)
	16.80	5.28			Smectite(.6S)
	19.75	4.50	19.70	4.51	Smectite(.6S)
	20.80	4.27	20.80	4.27	Quartz
			25.25	3.53	Anatase(?)
	26.55	3.36	26.60	3.35	Quartz
	26.60	3.36	28.05	3.18	Smectite(.6S)
Jm-9	5.30	16.67	7.20	12.28	Smectite(.8S)
	8.85	9.99	8.70	10.16	Illite
	10.35	8.55			Smectite(.8S)
	12.35	7.17	12.40	7.14	Kaolinite
	16.00	5.54	17.75	5.00	Illite
	19.65	4.52	19.85	4.47	Illite
	20.80	4.27	20.85	4.26	Quartz
	24.85	3.58	24.95	3.57	Kaolinite
	26.60	3.35	26.65	3.35	Quartz
	29.45	3.03	29.45	3.03	Calcite

SAMPLE	GLYCOLATED		NON-GLYCOLATED		INTERPRETATION
	2θ	d(Å)	2θ	d(Å)	
Jm-10	5.10	17.33	6.80	13.00	Smectite(1.S)
	10.40	8.51			Smectite(1.S)
	12.35	7.17	12.30	7.20	Kaolinite
			14.45	6.13	Smectite(1.S)
	15.90	5.57			Smectite(1.S)
			18.35	4.83	Smectite(1.S)
			19.65	4.52	Smectite(1.S)
	20.80	4.27	20.75	4.28	Quartz
			24.95	3.57	Kaolinite
	26.60	3.35	26.55	3.36	Quartz
	26.60	3.35	28.85	3.09	Smectite(1.S)
Jm-11	5.35	16.52	7.10	12.45	Smectite(.5S)
	8.85	9.99	8.80	10.05	I/I-S
	12.40	7.14	12.35	7.17	Kaolinite
	17.70	5.01	17.70	5.01	I/I-S
	29.80	4.48	19.80	4.48	I/I-S
	20.85	4.26	20.80	4.27	Quartz
	24.90	3.58	24.80	3.59	Kaolinite
	26.65	3.35	26.60	3.35	Quartz
Jm-12	5.10	17.33			Smectite(very weak)
	8.85	9.99	8.80	10.05	Mica(weak)
	12.40	7.14	12.35	7.17	Kaolinite
	18.80	4.72			?
	20.90	4.25	20.90	4.25	Quartz
	24.90	3.58	24.90	3.58	Kaolinite
	26.65	3.34	26.60	3.35	Quartz
	29.45	3.03	29.40	3.04	Calcite
Jm-13	5.20	17.00	7.15	12.36	Smectite(.6S)
	19.80	4.47	19.80	4.47	Smectite(.6S)
	20.80	4.27	20.80	4.27	Quartz
	26.55	3.36	26.60	3.35	Quartz
	26.60	3.35	28.00	3.19	Smectite(.6S)
Ja-14	5.85	15.11	6.25	14.14	14Å(w)
	8.85	9.99	8.85	9.99	Illite
	12.45	7.08	12.50	7.08	Kaolinite
	17.80	4.98	17.80	4.98	Illite
	26.65	3.36	26.55	3.34	Quartz
	26.95	3.31	26.90	3.31	Illite
	27.90	3.20	27.90	3.20	Feldspar
	29.40	3.04	29.40	3.04	Calcite

SAMPLE	GLYCOLATED		NON-GLYCOLATED		INTERPRETATION
	2θ	d(Å)	2θ	d(Å)	
Jtg-15	8.35	10.59	8.35	10.59	I-S(weak)
	8.90	9.94	8.70	10.16	I-S
	27.75	5.00			I-S
	19.70	4.51	19.95	4.45	I-S
	18.70	4.75			I-S
	20.80	4.27	20.85	4.26	Quartz
	23.05	3.86	22.95	3.88	Calcite
	26.60	3.35	26.60	3.35	Quartz
	27.45	3.25	27.40	3.26	Feldspar
	29.40	3.04	29.35	3.04	Calcite
Jtg-16	5.05	17.50	8.60	10.28	Smectite(weak)
	8.80	10.05	8.85	9.99	Illite(weak)
	12.50	7.08	12.45	7.11	Kaolinite
	17.70	5.01	17.90	4.96	Illite
	18.70	4.75	18.70	4.75	Illite
			19.85	4.48	Illite
	20.85	4.26	20.85	4.26	Quartz
	26.55	3.36	26.55	3.36	Quartz
	27.70	3.22	27.95	3.19	?
	29.35	3.04	29.40	3.03	Calcite
Jtg-17			8.45	10.46	I/I-S
	8.85	9.99	8.75	10.11	I/I-S
	12.45	7.14	12.40	7.14	Kaolinite
	17.70	5.01	17.70	5.01	I/I-S
	18.70	4.75	18.75	4.73	I/I-S
	19.90	4.46	19.80	4.47	I/I-S
	20.80	4.27	20.80	4.27	Quartz
	25.10	3.55	25.10	3.55	Kaolinite
	26.65	3.34	26.55	3.36	Quartz
	27.65	3.23	27.60	3.23	?
	29.40	3.04	29.35	3.04	Calcite
Jtg-18	6.05	14.61	8.50	10.40	I/I-S(weak)
	8.85	9.99	8.85	9.99	I/I-S
	12.35	7.17	12.45	7.12	Kaolinite
	17.75	5.00	17.70	5.01	I/I-S
	18.60	2.42	18.70	4.75	I/I-S
	20.80	4.27	20.80	4.27	Quartz
	25.00	3.56	25.15	3.54	Kaolinite
	26.60	3.35	26.60	3.35	Quartz
	27.90	3.20	27.90	3.20	?
	29.35	3.04	29.40	3.04	Calcite

SAMPLE	GLYCOLATED		NON-GLYCOLATED		INTERPRETATION
	2θ	d(Å)	2θ	d(Å)	
Jtg-19			8.40	10.53	I/I-S(weak)
	8.80	10.05	8.85	9.99	I/I-S
	12.40	7.14	12.40	7.14	Kaolinite
	17.70	5.01	17.80	4.98	I/I-S
	18.70	4.75			I/I-S
	19.75	4.50	19.80	4.48	I/I-S
			23.80	3.74	I/I-S
	20.85	4.26	20.85	4.26	Quartz
	25.15	3.54	25.10	3.55	Kaolinite
	26.30	3.39			?
	26.60	3.35	26.60	3.35	Quartz
	27.55	3.24	27.75	3.21	?
	27.90	3.2-	27.90	3.04	Feldspar
	29.40	3.04	29.35	3.04	Calcite
Jtg-20	5.00	17.20	7.60	11.63	Smectite(weak)
	8.85	9.99	8.80	10.05	I/I-S
	12.40	7.14	12.30	7.20	Kaolinite
	17.70	5.01	17.70	5.01	I/I-S
	18.70	4.75	18.55	4.78	I/I-S
	19.90	4.46	19.70	4.51	I/I-S
	20.85	4.26	20.80	4.27	Quartz
	25.15	3.54	25.10	3.55	Kaolinite
	26.65	3.34	26.60	3.35	Quartz
	27.45	3.25	27.40	3.26	?
	27.90	3.20	27.90	3.20	?
	29.40	3.04	29.45	3.03	Calcite
Jm-21	5.10	17.33	7.10	12.45	Smectite(.6S)
	15.80	5.61			Smectite(.6S)
	19.65	4.52	19.75	4.50	Smectite(.6S)
	20.80	4.27	20.80	4.27	Quartz
	26.55	3.36	26.60	3.35	Quartz
	28.40	3.14	28.05	3.18	Smectite(.6S)
	29.35	3.04	29.40	3.04	Calcite

	Smectite	Illite	Kaolinite	Chlorite	Mixed-layer
Ja-1			x		x
Ja-2					x
Ja-3			x		x
Ja-4			x		x
Ja-5			x		x
Ja-6			x	x	
Jm-7	x				
Jm-8	x				
Jm-9	x	x	x		
Jm-10	x		x		
Jm-11	x		x		x
Jm-12	x		x		
Jm-13	x				
Ja-14		x	x		
Jtg-15					x(w)
Jtg-16	x(w)	x(w)	x		
Jtg-17			x		x
Jtg-18			x		x
Jtg-19			x		x
Jtg-20	x(w)		x		x
Jm-21	x				

Table 4. Distribution of clay groups. (w) indicates a weak peak.

CONCLUSION

On the basis of the results of my study it appears that clay minerals can be used to differentiate the Arapien, Twist Gulch, and Morrison Formations. Generally, the Morrison is distinctive in that it contains smectite. The Arapien can be distinguished from the Twist Gulch by the better quality and greater abundance of mixed-layer clays.

SUGGESTIONS FOR FURTHER RESEARCH

More detailed research of the clay mineralogy of the formations might yield differences within the major clay groups. In addition, there is probably enough biotite present in the Morrison(?) to date the rocks radiogenically[1], which could then be used as a factor in determining its equivalency with the Morrison in other areas.

[1] Personal comment by Dr. K. O. Stanley ask Sutter or Roland who might kno

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